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The Metallurgist.

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Casting.

WITH very few exceptions metal manufacture commences with a casting process. This may be of a very simple kind, such as the running of pig iron into the roughly moulded pig bed, or the slightly more refined process of running molten copper into open wire-bar moulds, while, on the other hand, it may be a difficult and critical operation, such as the production of large or elaborate castings.

Scientific metallurgists have long since recognised that the phenomena which occur in all these cases are governed by the same laws that determine the way in which molten metal solidifies; unfortunately, the detailed application of these laws is very difficult to trace, and an immense amount of study has been devoted to the subject, both from the scientific and the practical point of view. The range of problems is large. We have, for example, the whole question of segregation, which, perhaps, finds its most acute expression in large steel ingots, while in non-ferrous metals we are frequently troubled with the phenomena loosely described as "inverse segregation." But, even apart from these problems, the more rudimentary task of providing methods of casting which will produce entirely sound and satisfactory objects frequently presents the gravest difficulties. It is not, perhaps, too much to say that there is no branch of metallurgical industry in which difficulties in the casting stage do not cause serious trouble and loss. The causes of these difficulties vary widely. In some cases they reside in the nature of the metal, as, for example, where the presence or absence of gas leads to defects. In other cases, troubles arise from contraction, from coarseness of structure, or from the formation of lines of weakness or of actual fissures.

While the final solution of these problems is not likely to be attained until a much deeper insight into the fundamental principles governing all these processes has been obtained by more prolonged and intensive investigation, considerable progress has been made by the development of special casting methods adapted to meet particular requirements. Some of these are of great interest and have already proved of much practical importance. For example, the success of the water-cooled mould for many purposes has disposed of one group of difficulties such as those which arise from the warping and cracking of metallic moulds in the course of continued use. Another interesting development has been that of the "Durville" process, in which molten metal, first poured into a special ladle attached to the mould, is then made to flow steadily into the mould by tilting it and the ladle simultaneously. Here the principle employed is mainly that of a very steady and comparatively slow filling of the mould in such a manner that the surface skin on the liquid metal shall not be broken. Hitherto this process has been confined mainly to alloys of copper containing an appreciable proportion of aluminium, and it has been used only for the casting of simple billets or bars. The principle in itself, however, would seem to be capable of application not only to many other metals, but also to the filling of moulds of more complicated shape. Whether it can be used successfully in connection with sand moulds is, perhaps, another question, but the underlying principle should be capable of extension in that direction.

A different principle has been developed in what is widely known as the "R.W.R." slab casting process of the V.A.W. Company in Germany. Here the mould is entirely filled with liquid metal, the mould itself being sufficiently heated to prevent immediate solidification. The flat top of the mould is then covered with a copper plate, the whole is inverted, and the copper plate is immediately subjected to rapid water cooling. The consequence is that a dendritic structure develops, starting from the copper plate and pushing upward before it gaseous and other impurities. It has, however, been found that the coarse dendritic structure formed in this way is liable to contain fissures between the large crystals, and this has been overcome in the patented process by means of vibration which is sufficient to break up the growing dendrites into a mass of fine equi-axed crystals.

To what extent the above method, which is daringly original in conception, is likely to be successful even for its own immediate purpose, or how far the principle which it embodies can be extended usefully for other purposes, remains to be seen. All these developments, however, are interesting indications of the need for improved casting methods, and of the enterprise and effort which are being devoted to the subject by practical metallurgists. Fortunately, these practical men are basing their efforts upon a sound appreciation of the scientific principles, so far as they are yet known, which underlie the processes in question. It would seem that there is need here not only for much more research, but for further and even fuller co-operation between the investigator and the designer and inventor. The first is primarily concerned with determining the laws which govern the phenomena in question, while the one object of the latter is to produce better castings—whether they be billets, slabs, or moulded material—and to produce them more cheaply and quickly than his predecessor.

The Surface Film.

ONE of the most striking metallurgical developments of the last decade has been that of corrosion resisting materials. This period has witnessed the great development of the chromium and nickel-chromium rust-resisting steels, and also that of anodised aluminium and aluminium alloys. It is interesting to observe that in the rust-resisting steels resistance to corrosion is attained by adding to the metal one or two specific alloying elements, namely, chromium and nickel. On aluminium a protective effect is obtained by a surface treatment; although certain alloying elements appear to be favourable and others unfavourable to the development of a resistant anodic film, the result in this case is not achieved by alloying additions to the metal. None the less, the mechanism by which resistance to corrosion is obtained in both cases is, ultimately, similar. It has been shown that in the rust-resisting steels, as much as in the anodised aluminium, protection is due to a tough and continuous surface film which is itself chemically resistant to a great many attacking agencies and is thereby capable of protecting the underlying metal. It is not surprising to find that the tangible existence of these protective surface films has led to the view that all metals become covered, on exposure to the atmosphere, with some sort of surface film which always, in a greater or lesser degree, acts as a protective medium against corrosive attack.

This is not the place to bring forward evidence in support of this view, or in opposition to it, but it seems desirable to point out that a generalisation of this kind may be incorrect and may possibly lead to serious misconception. If we look into the matter we find that the films which are formed on many substances by the process known as "adsorption" are of a special kind. For instance, a film of fatty substance may be formed of small or even molecular thickness, and in that molecular layer, as Langmuir and others have shown, the elongated molecules of the fat are frequently all arranged in one particular way, being attached at one end by something which we may, or may not, regard as a chemical bond, to the material beneath. It is difficult, however, to regard an adsorbed layer of this kind as being of the nature of a continuous film because, in fact, we may have to think of it as a collection of molecules attached to individual atoms or molecules of the material upon which it is adsorbed. The question arises what degree of cohesion exists between the adjacent molecules in a film of this kind. Where the film consists of a material which we ordinarily regard as a liquid, such as an oil, we are naturally inclined to think of it as a continuous film of liquid attached, for example, to a metal surface. It may, however, be found that, in fact, the lateral cohesion between adjacent molecules is very small compared with the adhesion of each molecule to the solid beneath. It is interesting to inquire what would occur if a mechanical stretching took place in the absence of a supply of further molecules of the adsorbed substance. It is quite possible that, in some circumstances, the molecules of the surface layer would retain their attachment to the individual atoms of metal with which they had originally been connected, and that consequently the surface layer might lose its continuity entirely.

The case of the oxide or similar film on metal exposed to the atmosphere is, perhaps, somewhat different. The chemical bonding between oxygen and atoms of the metal is probably very definite, while the lateral cohesion between adjacent atoms or molecules of the surface layer is likely to be relatively very weak. In these circumstances, it is difficult to think of such a surface layer as being in the ordinary sense a continuous film, and the fact that the great majority of such films have little or no protective action is thus readily understood. Apparently, it is only when a surface layer has a particular composition that a continuous film having a protective effect is formed. This distinction is of importance when we have to consider, for example, the very important phenomena of corrosion-fatigue. The combined effect of alternating stresses and slightly corrosive conditions is often ascribed to the supposed rupture, at a number of points, of the original protective film on the metal under alternating stress. We would suggest that it yet remains to be shown that, except in special cases of corrosion-resisting materials, such a surface film has any appreciable degree of continuity even when a metal is at rest and that so long as the deformation of the metal is of an elastic nature all that may happen is a widening of the interatomic or intermolecular spacing of the surface layer. So long as the elastic stretching of the metal is uniform over a given area, there would, therefore, be no reason to anticipate any actual fissures in the surface layer, nor, indeed, anything that could be fairly described as a "rupture" of that layer. The problem is, unfortunately, one of very great difficulty, but it is highly important that the advantages which we gain from an advance in our knowledge such as that constituted by the discovery and demonstration of surface films on rust-resisting steels should not be rashly generalised to afford explanations of cases in which, in reality, these phenomena may not be involved directly. The explanation of corrosion-fatigue, therefore, which is at present so widely accepted, should, we suggest, be carefully scrutinised and, if possible, tested by experiment before too much reliance is placed upon it.

The Electro-deposition of Beryllium.

AMONG the properties of beryllium which have been discovered during the investigations which have been carried on during the last decade is the high resistance of the metal to tarnish. This property has stimulated interest in the possibility of the electro-deposition of the metal. Owing to the position of beryllium in the electro-chemical series, it seems unlikely that it can be successfully deposited from aqueous solutions. In its technical production it is only possible to obtain the metal in a compact form by fusion electrolysis at temperatures above its melting-point (1281 deg. Cent.). At lower temperatures the metal does not adhere to the beryllium cathode, but accumulates on the surface of the bath as powder.

Working independently, however, Sloman,* of the National Physical Laboratory, and Fischer,† of the Siemens-Halske Laboratories in Berlin, have shown that if the cathode consists of some metal other than beryllium, electro-deposition of the metal from a fused bath is possible under certain conditions at

* *Journal*, Institute of Metals, Vol. 49, Part 2, page 365, 1932.

† Wissenschaftliche Veröffentlichungen aus dem Siemens Konzern, Vol. 8, Part 1, page 69, 1929.

temperatures well below its melting-point. The results, which are of considerable importance, have been confirmed by Fischer and Schwan in their most recent publication (*Metallwirtschaft*, No. 14, April 7th, 1933).

The most satisfactory bath consists of three parts of beryllium fluoride with one part of sodium fluoride, which is maintained in a liquid state at a temperature above 500 deg. Cent. The bath may be held in a graphite crucible, which at the same time serves as the anode. The cathode consists of a rod or strip of copper or some other metal. A small quantity of sodium separates with the beryllium. This does not contaminate the deposit, but burns at the surface of the bath. The presence of water in the bath is very deleterious, and may even completely inhibit the deposition. The final drying of beryllium fluoride, which is very hygroscopic, is a matter of some difficulty, but has been overcome by the addition to the bath of a small quantity of ammonium fluoride. Residual water is rapidly removed as gaseous ammonia and hydrogen fluoride.

Among the factors which exert most influence on the current efficiency are temperature of the bath, current density at the cathode, and duration of the electrolysis. During a 15-minute period, using a copper cathode and a current density of 1150 ampères per square metre, the efficiency at 550 deg. Cent. is only 20 per cent., while at 800 deg. Cent. it is as high as 88 per cent. Above this temperature, however, it begins to fall off again somewhat rapidly. With the same period of electroylsis and a temperature of 800 deg. Cent., the efficiency with current densities up to 1000 ampères per square metre is 90 per cent.; with larger densities it decreases, falling to 50 per cent. at 3500 ampères per square metre, and as low as 10 per cent. at 7750 ampères per square metre. Moreover, at the higher current densities the deposit is not smooth, but irregular and coarsely crystalline. The low efficiency is due to the fact that the beryllium is deposited for the most part as powder in the neighbourhood of the cathode.

In connection with the influence of the duration of the electrolysis it has been shown that the weight of beryllium deposited per minute decreases more and more rapidly with the period which has elapsed since the commencement, until a time is reached after which no further deposition occurs. With a copper cathode, a temperature of 750 deg. Cent. and a current density of 1150 ampères per square metre, this state is reached at the expiration of about two hours, and the maximum thickness of deposit obtainable is of the order of 0·1 mm.

In regard to the mechanism of the deposition, Sloman suggested that the possibility of obtaining compact beryllium deposits by this method depends entirely on the cathode being of such a material as to enable the beryllium readily to diffuse into and alloy with it. This suggestion was based on an examination of the deposits obtained on copper at different temperatures with correspondingly different rates of diffusion, and also on the failure of all attempts to deposit the metal on cathodes of beryllium or graphite where the above conditions were not fulfilled.

This is now confirmed by Fischer and Schwan, who, in the light of a fuller investigation, correlate more completely the types of deposit obtained under various conditions with the rate of diffusion of beryllium into the cathode metal. In the case of copper, with which most of the work has been carried out, the rate of diffusion increases with rising temperature, and the current efficiency is accordingly higher at the higher bath temperatures. It is not, however, obvious why a maximum efficiency should occur at about 800 deg. Cent., unless it be connected with the possible partial liquefaction above this temperature of the copper-beryllium alloy formed by diffusion.

The effects on the efficiency of changes in current density at constant temperature are also consistent with the theory. If the rate of deposition is greater than the rate of diffusion, the excess beryllium cannot adhere to the cathode, the surface of which is already saturated with the metal, and the efficiency is thus lowered. The optimum rate of deposition is equal to or somewhat less than the rate of diffusion with the particular conditions employed.

With regard to the influence of the duration of the electrolysis, it is apparent that at the commencement pure beryllium is in contact with pure copper, and that the composition gradient is a maximum. As the electrolysis proceeds and diffusion occurs, the gradient of composition at the surface of the cathode becomes less and less steep with a corresponding decrease in the rate of diffusion, and hence in the current efficiency, until ultimately zero value is approached. The beryllium subsequently separated from the bath will not adhere to the cathode, and the maximum thickness of deposit has been obtained.

The surface of the deposits on copper, after a short period of electrolysis (15 minutes), may be either steel-grey or yellow in colour. The former, which consists either of pure beryllium or of a very high percentage beryllium alloy, is obtained in the temperature range of 550 deg. to 750 deg. Cent., while the latter, which consists of an alloy containing considerably less beryllium, is formed at temperatures above 750 deg. Cent., and corresponds to the higher rates of diffusion at these temperatures. If the period of electrolysis is prolonged (one hour), the surface at all temperatures is steel-grey in colour; this results from the slowing down of diffusion as the composition gradient becomes less steep. In all cases there is a region beneath the surface which is yellow in colour, and which merges into the central core of pure copper.

As might be expected, the deposits are very firmly attached to the basis metal, and are extraordinarily hard and strong. The mechanical properties of the resulting material are largely determined by those of the beryllium alloy in the outer layers. Considerable interest attaches to electro-deposits of this type, and, despite certain difficulties which are inherent in the method, such as the relatively high temperature of the bath, they should have many industrial applications, as, for instance, where the high electrical conductivity of pure copper is required, coupled with the strength and elasticity of the copper-beryllium alloys. This has a particular bearing on the future construction of overhead power and telephone cables. Again, for certain purposes, it may be necessary or desirable to protect a metal by a corrosion and tarnish-resisting film of beryllium itself.

A further point of interest in connection with these deposits is the effect of subsequent heat treatment. This leads to the gradual diffusion of the beryllium throughout the whole mass with the formation of a homogeneous alloy containing a low percentage of beryllium. This process, however, is very slow, and may require several weeks at about 800 deg. Cent. before the specimen approaches homogeneity.

As pointed out above, most of the work to date has been carried out with copper as the cathode. Other metals have, however, been employed. It has

been observed by Hevesy* that the rate of diffusion of one metal into another is greater the further the two metals are apart in the periodic system. The composition gradient referred to above is therefore not the only factor which influences the rate of diffusion at constant temperature. Hevesy's observation is in accordance with the results obtained by the use of nickel, iron, bronze, brass, and aluminium cathodes in the present connection. While deposits of beryllium can be obtained on each of the above metals, the rates of diffusion in every case are less than with copper. This is particularly true for aluminium, which, of the metals employed, is the nearest to beryllium in the periodic system.

The Quenching of Steel.

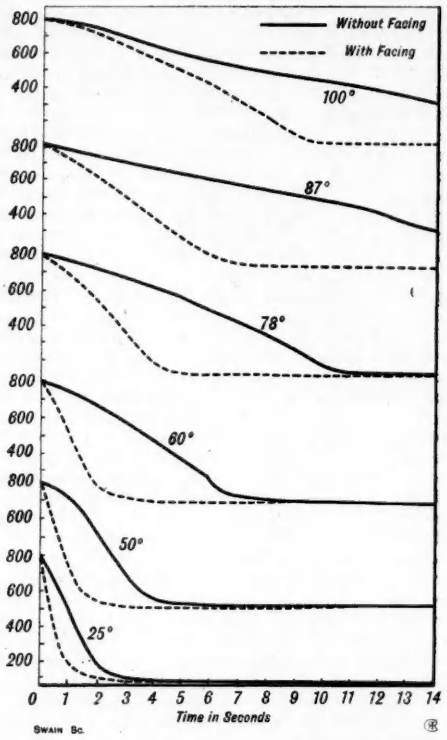
THE effect of various quenching media and of the condition of the steel itself on the rate of cooling, and, consequently, upon the physical properties of the steel, have received much study. The development of methods whereby time-temperature curves can be taken during the quenching process has materially assisted this type of investigation, as exemplified by the early work of Le Chatelier and the later work of Benedicks and others. From these results it has emerged that the vaporisation of the liquid used for quenching plays an important part, and it has at least been suspected, if not actually proved, that a film of vapour, such as steam, maintained between the hot steel and the cooling liquid very materially retards the rate of cooling.

An interesting further step in this type of investigation has been made in Japan by S. Sato.† Particular interest attaches to this paper because it describes an investigation by thoroughly scientific means of a process which had been discovered in past times by Japanese craftsmen. This process consists in "facing" pieces of steel which are to be hardened by quenching, and it is claimed by the Japanese workmen that without this "facing" the full hardness of the steel cannot be obtained. The "facing" employed consists of a thin wash of a more or less earthy material, among which the substance known as "Tonoko," which is really the fine powder resulting from the wear of a certain type of Japanese grindstone, plays an important part. The nature of this ingredient, incidentally, throws a good deal of light upon the manner in which this particular process came to be developed, probably as the result of an accidental discovery.

The Japanese author (Sato) has previously described an autographic dilatometer capable of recording the rapid changes of length which occur during quenching. This instrument has been adopted with small changes for taking time-temperature curves during rapid cooling, and with it a series of curves has been obtained for steel quenched in a considerable variety of cooling liquids, and with the surface both faced and clean. The author points out clearly that the facing, to be effective, must be applied in a thin coat, and to steel so treated that the coating adheres and is neither flaked off nor washed off during quenching. For this purpose the surface of the steel is initially roughened, after having been finished by machining, by means of 90-mesh carborundum powder mixed with water. For the coating itself a wide variety of substances was used, some seventy varieties being tested, and the result was always to increase the velocity of cooling of the specimens. One of the most favourable mixtures had the following composition :—

Fire clay	75 gr.
Graphite	25 gr.
Tonoko	30 gr.
Borax (anhydrous)	14 gr.
Water	200 c.c.

The effect of the "facing" is clearly seen in all the cooling curves, but is most marked for hot water. The curves for water at various temperatures are reproduced in the figure. With other media the



COOLING CURVES WITH AND WITHOUT FACING

effect was not so large, disappearing almost entirely in the case of refined rape oil.

In his summary the author states that an unfaced specimen heated to a high temperature is, when quenched, at once covered with a vapour envelope given off by the cooling medium, and as the vapour is a bad conductor of heat the cooling of the specimen is thereby greatly retarded until the envelope begins to break and direct contact with the specimen takes place, and then there is an abrupt increase in the cooling velocity which is indicated by a break in the time curve results. Faced specimens are never enveloped by vapour film, and therefore their cooling is very rapid and uniform throughout the specimen. Thus, the old technique of quenching steel specimens with facing is very useful. It gives them an intense and uniform hardening. The existence of the envelope

* "Zeit. Electrochemie," Vol. 37, page 528, 1931.

† "On the Effect of 'Facing' on the Cooling Velocity of a Specimen during Quenching," by Seikichi Sato. Science Reports of the Tohoku Imperial University, Series 1, Vol. XXI., No. 4.

of vapour is further demonstrated by a series of photographs showing the appearance of the hot piece of steel while immersed in the quenching medium, both when the steel is faced and unfaced.

This work is not only interesting because it demonstrates the justification of an old-time handicraft practice, but also because it may afford possibilities for improved hardening in many ordinary industrial operations. The "facing" cannot, of course, be applied on a scaly or oxidised surface, and it remains to be seen whether the "facing" will survive either the heating and furnace atmosphere or the mechanical handling to which commercial steel is subjected prior to quenching. Some development of the process, however, may make it possible to avoid scaling, oxidation, and surface decarburisation in steel which has to be quenched, while allowing a greater and more uniform hardness to be obtained. It is also possible that the formation of cracks may be minimised by the more uniform surface cooling which apparently can be obtained in this way. It is certainly a process which those who are concerned with the hardening of steel would do well to study.

Solid Solutions.

Much importance still attaches to the study of solid solutions from the point of view of their internal structure. Up to the present time only two types of solid solution have been established with certainty. The first is that in which the atoms of the dissolved metal take the place of some of the atoms of the solvent metal, thus forming a solid solution by substitution; in the second or interstitial type the atoms of the dissolved substance are located in the interstices of the lattice of the metal. In this latter type the only well-established example is that of austenite in steel. The exact study of the structure of a solid solution, from the atomic point of view, is undertaken by calculating the density of an alloy of known composition from the measured lattice spacing and the known weights of the atoms. If this is compared with a careful determination of the true density of the alloy by direct measurement, it becomes possible to decide whether the supposed arrangement of the atoms upon which the calculation has been based is correct.

In the great majority of cases so far investigated, the direct measurements of density and the calculated values based upon X-ray analysis and the substitution theory, have given excellent agreement, but in a few instances observations have been made which do not appear to fall correctly into this relatively simple system and the suggestion has been put forward that in these cases possibly groups of atoms, perhaps of the nature of a compound molecule, replace a number of atoms on the lattice of the solvent metal. While this would still be, in a sense, a solid solution of the substitution type, the substitution would be of a more complex nature, and the resulting densities would be appreciably different. In checking such measurements, however, the determination of the true density of an alloy by direct measurement has proved to be a difficult matter. When an alloy is melted and allowed to solidify it is generally found that the density is comparatively low, and this is ascribed to the inclusion of gas bubbles or the formation of shrinkage cavities, and in the great majority of cases this is no doubt correct. The device is generally adopted, therefore, of subjecting the metal to a considerable degree of cold work followed by or alternated with annealing sufficient to restore the material to its normal equiaxed crystalline condition. In this way a maximum density can generally be obtained which is regarded as the true density of the material free from cavities. It is this density which is used for comparison with calculations from X-ray data.

A particularly interesting example of an investigation of this kind has just been published by C. H. Barrett in the May number of *Metals and Alloys*, page 63. This deals with the alloys of aluminium and silver and refers to the fact that certain other observers (Phelps and Davey and others) had found a discrepancy between the calculated and the measured densities too great to be accounted for by experimental error. The American author, therefore, goes to considerable length in his endeavour to secure accurate values, both on the X-ray side and in regard to the measurement of density.

Using silver of 99·99 per cent. purity, and aluminium of 99·97 per cent., cylindrical ingots weighing 120 grammes each were made under conditions carefully designed to avoid contamination. These ingots were turned on a lathe, reducing their diameter by $\frac{1}{8}$in., and were then annealed in graphite at 750 deg. Cent. for one week. Each day they were removed and hammered while hot, the reduction being about $\frac{1}{16}$in.; they were then quenched, filed clean, and the annealing continued. At the conclusion of this treatment the ingots were from $\frac{1}{8}$in. to $\frac{3}{16}$in. thick, having been reduced from an initial diameter of $\frac{5}{16}$in. The precaution was also taken to remove all surface contamination, while the absence of segregation was established by analyses of samples from both ends of each ingot. A corresponding degree of care was taken to secure the most accurate measurement of lattice dimensions.

As a result of this careful work Mr. Barrett finds that the densities calculated on the simple substitution theory for the alloys of silver and aluminium agree, well within the error of experiment, with the densities found from direct measurement, so that a complication based upon imperfect data has been swept aside in a satisfactory manner.

The Effect of Grain Boundaries on Equilibrium.

In the determination of the phase boundaries, or limits of solubility, in the equilibrium diagram of a system of alloys it has generally been assumed that the results obtained are independent of the grain size, and that the same equilibrium diagram would be applicable to single crystals and to polycrystalline material. Recent research work seems to indicate that such an assumption must be accepted with reservations, as effects of a measurable magnitude, apparently due to the presence of grain boundaries, have been observed. P. Wiest* has determined the limit of solubility of silver in copper by an X-ray method and finds that a single crystal specimen is capable of holding more silver in solution than a polycrystalline sample. The expansion of the copper space lattice per atom of silver in solution is less for the single crystal than for the polycrystalline specimen; thus at 700 deg. Cent. a single crystal can hold 7 per

* Zeitschrift für Physik, Vol. 74, p. 225, 1932.

cent. by weight of silver in solution, while a polycrystalline specimen is saturated at a concentration of 5·5 per cent. silver. The limiting value of the lattice parameter at this temperature is the same, 3·625 Å, for both types of material. At lower temperatures, however, the single crystal is capable of greater distortion, so that, for instance, at 400 deg. Cent. we find the limiting values of the parameter to be 3·610 Å for the polycrystalline and 3·612 Å for the single crystal, the corresponding concentrations being 0·6 per cent. and 1·6 per cent. by weight of silver. The same author* has also examined a series of alloys of gold and silver and has obtained similar results. These metals are mutually soluble in all proportions and have nearly equal lattice parameters, while the parameter-composition curve has a minimum at 75 atomic per cent. gold. According to Wiest, the single crystal parameter-composition curve lies above the same curve for polycrystalline material, the difference being greatest at 75 atomic per cent. gold. For alloys of this composition the following figures, taken from his paper, illustrate the sort of effect observed :—

Single crystal.	Polycrystalline.
4·0669	4·0646
4·0677	4·0646
4·0671	4·0643
4·0675	4·0643
Mean.. 4·0673	4·0645

It will be seen that the parameter values from the four different single crystal specimens differ from their mean by ±0·0004 Å, and that the four determinations from polycrystalline material lie within even closer limits. The two mean values, however, differ by 0·0028 Å, nearly ten times the error of observation. This result is of great interest and appears to dispose of the idea that the different parameter values observed in the case of the copper-silver alloys may be due to the mechanism of precipitation of a second phase (or the form in which it separates), because we are here dealing with a continuous series of solid solutions and there is no second phase present. The fact that parameter measurements of the above accuracy can be made indicates that equilibrium has, in fact, been attained, so that it does not appear possible that the effect is due to coring or inhomogeneity.

These results have recently been extended by Phillips and Brick† to an alloy system of technical importance. These authors have made a careful X-ray study of the solubility of copper in high purity aluminium. The method of preparation of their material is fully described in the paper, which should be referred to for details. Here it will suffice to say that they examined, by accurate X-ray methods, six alloys in the following states :—

(*a*) Fine-grained polycrystalline wire,
(*b*) Coarse-grained polycrystalline wire,
(*c*) Single crystal wire,
(*d*) Fine single crystal powder, particle size comparable with grain size of (*a*),
(*e*) Coarse single crystal powder, particle size comparable with grain size of (*b*).

These materials were all examined promptly after quenching from 540 deg. Cent., and also after annealing for suitable periods at a series of lower temperatures, the treatment being continued until no further change of lattice parameter was observed. Six different alloys were used with copper concentrations between 1·02 and 5·65 per cent. by weight. The observations on the materials quenched from 540 deg. Cent. give a linear relation between parameter and composition in all cases, but the points for different states of subdivision do not all lie on the same straight line. For the same copper concentration the lattice parameter of a single crystal of any size is always larger than that of a polycrystalline aggregate. The materials in states (*c*), (*d*), and (*e*) in the above list all yield substantially the same parameter-composition line, while the values obtained from alloys in state (*b*) lie between those given by (*a*) and the remainder. The differences in observed parameter are quite large compared with the errors of experiment ; for instance, a 4 per cent. alloy in the polycrystalline state has a parameter of 4·0326 Å, while the same lattice measurement of a single crystal requires the solution of 5·5 per cent. copper, and the 4 per cent. single crystal has an observed parameter of 4·0350 Å. Since the most obvious difference between the metal in state (*a*) and the states (*c*), (*d*), and (*e*) is that the former possesses grain boundaries the authors conclude that the presence of these boundaries is the cause of the effect they have observed.

This very interesting paper is concluded by a determination of the solid solubility limit of copper in aluminium for the polycrystalline and single crystal materials. The solubility limit for the former is somewhat lower than that in the diagram of Dix and Richardson ; the authors do not question the accuracy of that diagram, but state that the discrepancy may be due to the different methods of determination. In the X-ray method there is always a relatively large amount of $CuAl_2$ present in the alloy under examination, while the usual metallographic method employs alloys in which little or no precipitation has taken place. The fact that the limiting parameter value is independent of composition, *i.e.*, of the quantity of $CuAl_2$ precipitated, suggests, however, that the discrepancy may be due to some other cause.

At temperatures above 400 deg. Cent. the solubility of copper is considerably greater in single crystals than in polycrystalline material. The solubility line for single crystals if produced would meet the eutectic horizontal (548 deg.) at a copper concentration of 7 per cent., but the authors suggest that the eutectic temperature may also be affected by the grain size, and for this reason they have not completed the extrapolation.

* *Ibid.*, Vol. 81, p. 121, 1933.

† *Journal* of the Franklin Institute, Vol. 215, p. 557, 1933.

Properties and Uses of Cobalt.

COBALT is being used to an increasing extent in the manufacture of special alloys, many of which have very important uses and applications. The actual consumption of the metal is comparatively small, but in recent years it has increased considerably. In a paper, published in the July issue of *Mining and Metallurgy*, B. E. Field has given some useful data regarding the properties of the metal and its uses. Cobalt was first isolated about the middle of the eighteenth century by Brandt. It is silvery white in colour and when pure has a density of 8·81 in the unworked condition. The Brinell hardness of the pure metal is 124, its atomic weight 58·97, and its melting point 1478 deg. Cent. The pure metal in the cast condition is reputed to have a higher tensile

strength than any other pure metal and a value of 34,400 lb. has been given for cobalt in the cast unannealed condition. On pure cobalt wire values upwards of 100,000 lb. per square inch have been obtained. Iron exerts a hardening effect on the metal and increases the strength. So-called pure cobalt contains 99·7 to 99·9 per cent. cobalt, while commercial cobalt contains from 96 to 98 per cent. cobalt, the chief impurities being carbon, nickel, iron and arsenic. Although the commercial metal is quite readily machined, giving curling chips, the chips from pure cobalt are short and indicate brittleness. The pure metal is difficult to work without preliminary heat treatment, but after cooling under pressure from 1100 deg. to 1150 deg. Cent., it can be worked between 500 deg. and 600 deg. Cent. The commercial variety of the metal can be worked readily at a red heat. The specific electrical resistance of pure cobalt is approximately five times that of copper, namely, $89 \cdot 64 \times 10^{-7}$ microhms/cm. cu. The metal is magnetic at all temperatures up to 1100 deg. Cent.

The metal has only been produced in commercial quantities during the present century, and even so it has been rather as a by-product. Most of the metal at the present time is obtained from Katanga ores. An alloy of copper, cobalt, and iron is produced, which is further refined at Oolen in Belgium, and a small amount of metal is refined electrolytically.

It has been known for over twenty years that the presence of cobalt improves the cutting properties of high-speed tool steel, and it has since been shown that the cutting quality of an 18 per cent. tungsten, 4 per cent. chromium steel, increases rapidly with an increase in cobalt up to 6 per cent., the best results, however, apparently being obtained when a fairly high percentage of vanadium is also present. Cobalt is also used in the manufacture of high-grade magnet steels, the replacement of part of the iron in ordinary tungsten magnet steel by cobalt producing much better permanent magnet material than had previously been known. A typical cobalt magnet steel of to-day contains 57 per cent. iron, 35 per cent. cobalt, 2 per cent. chromium, 4 per cent. tungsten, and 0·09 per cent. carbon. The most important property of this type of steel, which contains the compound Fe_2Co, is its permeability in medium fields, which is some 25 per cent. greater than that of pure iron or commercial grades of transformer steel.

Another important use for metallic cobalt is in the manufacture of Stellite, a non-ferrous alloy containing cobalt, chromium and tungsten, one of the outstanding properties of which is retention of hardness at elevated temperatures. This particular alloy is the most important cobalt alloy which has been developed on a commercial scale, and its manufacture accounts for a large proportion of the metallic cobalt consumption. The cutting qualities of Stellite are well known, and it is stated to be particularly suitable for cast iron, malleable iron, semi-steel, cast steel, brass, bronze, aluminium alloys and hard rubber, but its use on tough heat-treated alloy steels is more limited, and depends on the type of machining to be carried out. Successful use has been made of the wear-resisting qualities of the alloy in the process of hard facing or stelliting. The composition of the alloy is varied in order to produce different properties and some grades can be rolled and forged. The whole series of alloys is very resistant to corrosion, and they are used in food processing and other plants in chemical industry where resistance to wear and corrosion are essential.

A more recent development than Stellite has been the commercial production of sintered tungsten carbide alloys for use as cutting tools and dies. In these materials metallic cobalt in varying quantity is used as a binder. Although carbides other than tungsten, such as tantalum, are used, cobalt in most cases is employed as the binder.

A new cobalt cutting tool alloy, which contains about 25 per cent. cobalt, 30 per cent. tungsten, and 35 per cent. iron, has been developed in America, and was described in THE ENGINEER for April 7th, 1933. Some very useful properties are claimed for this material, but no information seems to be available yet regarding its commercial development. It is interesting, however, to note that it contains a large proportion of iron, for it has been considered that the presence of iron in Stellite is definitely detrimental to the retention of hardness at elevated temperatures. Another cobalt alloy has been developed and produced in America, under the name of Konel, as a substitute for platinum in oxide-coated thermionic cathodes. This alloy contains 70 per cent. nickel, 19·5 per cent. cobalt, 7·4 per cent. iron, and 2·8 per cent. titanium. Alloys of this type with a nickel plus cobalt content of 80 to 95 per cent. are stated to have high values for electrical resistivity and tensile strength, and to retain their strength well at high temperatures. Kanthal is another alloy which has been developed recently. It consists of cobalt, chromium, and aluminium, and is made in several grades. It has been used for the manufacture of heating elements for electrical resistance furnaces, and is stated to be serviceable for long periods up to temperatures of 1325 deg. Cent., which is considerably in excess of that at which furnaces heated with nickel-chrome elements can be operated.

Steel Melting in Coreless Induction Furnaces.

BARDENHEUER and Bottenberg, in a paper in the *Mitteilungen des Kaiser Wilhelm Institut für Eisenforschung*, Vol. 15, 1933, point out that the use of high-frequency furnaces by steel makers has been largely confined to the manufacture of special steels from high grade materials. There appears to have been little response in industry to the researches of Wever and Neuhauss and Hindricks*, which have shown that impurities could be removed from steel in coreless induction furnaces. Mention is also made of the work of Campbell† in England.

Bardenheuer and Bottenberg have shown that both phosphorus and sulphur can be removed from steel, not only in small laboratory furnaces, but also in a furnace of 300 kilos. capacity. In their general discussion of the problem, reference is made to the supposed coldness of the slag in coreless induction furnaces, and the consequent retardation of reactions between the slag and the metal. Accordingly, their experimental work was performed with a thick heat-insulating cover placed immediately above the slag level, and a furnace energised at such a frequency that a brisk circulation occurred in the metal bath.

* F. Wever and H. Neuhauss, Mitt. Kaiser-Wilhelm Institut für Eisenforschung Band 8 (1926), p. 171/79. F. Wever and G. Hindricks, Mitt. Kaiser-Wilhelm Institut für Eisenforschung Band 13 (1931), p. 273/89.

† D. F. Campbell, "High-frequency Steel Furnace," *J.*, Iron and Steel Institute, 122 (1930), p. 85/94.

Under these circumstances no sluggishness in the slag metal reactions is apparent.

Conditions essential for the removal of phosphorus from steel are formulated. The phosphorus is oxidised and sufficient lime is provided in the slag to combine with the oxidation products. It is essential to avoid the presence of any reducing agent which might extract the phosphorus from the slag. Fluorspar is added to the lime-rich slag in order to maintain sufficient fluidity during the dephosphorising process which is conducted at a moderate temperature. In this connection it is stated by the authors that the addition to the slag of 15 per cent. of fluorspar did not result in any undue attack on the furnace lining. On the other hand, a slag low in fluorspar but high

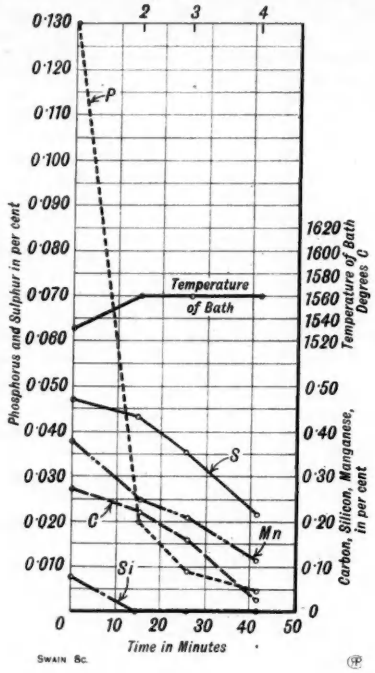


FIG. 1

in iron oxide content proved markedly corrosive. The furnace lining consisted of a mixture of magnesite with 10 per cent. of open-hearth slag.

In a small 15-kilos. furnace operating at 6300–8000 cycles, the phosphorus was diminished in a dead-mild steel from 0·59 to 0·02 per cent. in 50 minutes. Another small experimental melt containing 0·39 per cent. carbon and 0·13 per cent. phosphorus was then prepared, and subjected to the dephosphorising process. It was observed that so long as the bath contained appreciable quantities of carbon and manganese the phosphorus content fell slowly. Ultimately, the phosphorus was successfully removed. The 300 kilos. coreless furnace, operating at 500 cycles, was next utilised for the preparation of a melt which gave on analysis :—

0·27 per cent. carbon
0·07 per cent. silicon
0·38 per cent. manganese
0·13 per cent. phosphorus
0·047 per cent. sulphur

During 15 minutes treatment the phosphorus content fell from 0·13 to 0·02 per cent., and in 40 minutes to 0·004 per cent. The phosphorus removal is illustrated graphically in Fig. 1, which also indicates the diminution of other impurities in the steel as well as the temperature attained by the bath during the various stages of the process.

Samples of slag were taken at intervals (indicated by the numbers at the top of Fig. 1) and analysed. Thus, a sample taken after 15 minutes had elapsed contained 12·9 per cent. SiO_2 and 51·8 per cent. CaO, while a further sample extracted 11 minutes later gave 0·22 per cent. SiO_2 and 68·4 per cent. CaO. The sudden increase in basicity of the slag is due to a deliberate replacement of the slag which is designated in Fig. 1 as "Schlackenwechsel."

For the removal of the sulphur from steel a slag of the following approximate composition was adopted :—70 per cent. CaO, 8 per cent. Al_2O_3, 4·5 per cent. Si, 2·2 per cent. C, and 15·3 per cent. CaF_2. In spite of the high percentage of lime, no difficulties due to viscosity of the slag were encountered. A small experimental melt containing 0·97 per cent. carbon and 0·34 per cent. sulphur was first treated, and the sulphur content fell to 0·017 per cent. in 70 minutes. In the case of a steel containing 0·26 per cent. carbon and 0·081 per cent. sulphur, a treatment of 45 minutes duration lowered the sulphur content to 0·01 per cent. During this operation the percentage of silicon in the bath fell gradually while the carbon and manganese contents were practically unchanged. A large-scale experiment was then conducted in the 300-kilos. furnace with a steel bath containing 0·20 per cent. carbon and 0·12 per cent. sulphur. As will be seen in Fig. 2, a treatment lasting 32 minutes sufficed to lower the sulphur content to 0·014 per cent. Numerous slag samples were taken for analysis and at one stage of the treatment the original slag was replaced by material very low in silica.

In conclusion, the authors suggest that as the removal of impurities from steel usually involves exothermic reactions, the lower the working temperature (compatible with a reasonable speed of reaction), the more complete is the removal of impurities. Owing chiefly to the vigorous bath circulation, lower working temperatures can be successfully employed in coreless induction furnaces. The importance of operating this type of furnaces at suitable frequencies when removing phosphorus and sulphur from steel is emphasised.

In connection with the work just discussed, some interest also attaches to the description of a coreless induction furnace for vacuum melting, which is given by Bottenberg in the same publication. As is well known, small high-frequency furnaces operating under laboratory conditions are readily adapted for vacuum melting. Bottenberg states, however, that few commercial attempts have been made to melt under vacuum conditions in large coreless furnaces. This he attributes chiefly to the difficulties associated with the provision of large vacuum vessels. In a furnace of the usual type the vacuum vessel is situated inside the inductor coil and must therefore possess a negligible electricial conductivity. Silica or a non-porous variety of porcelain may be used in the construction of large vacuum vessels, which are necessarily costly. Further, their fragile nature may prove a source of danger in large-scale melting.

The author has constructed a coreless induction furnace in which the usual fragile non-metallic vacuum envelope is replaced by a relatively large steel container of 70 litres capacity. As will be seen

from Fig. 3, the lower portion of the cylindrical vessel practically surrounds the inductor coil, and is provided with a flanged joint for accommodating the upper portion of the vacuum casing when it is desired to seal the furnace. Vacuum tightness at the joint is attained by interposing a rubber ring.

The furnace inductor coil is capable of dealing with 10-kilo. melts, and measures 17 cms. approximately in diameter by 20 cms. in height. These dimensions permit of a considerable space between the outside of the inductor coil and the walls of the steel vacuum vessel. The electrical connections to the coil pass through specially sealed holes in the lower part of the vacuum container, which is also fitted with a flexible vacuum tube, 1in. in diameter. In the upper part of the vessel is an observation window and a special arrangement for making additions of alloying materials or flux while the furnace is in operation.

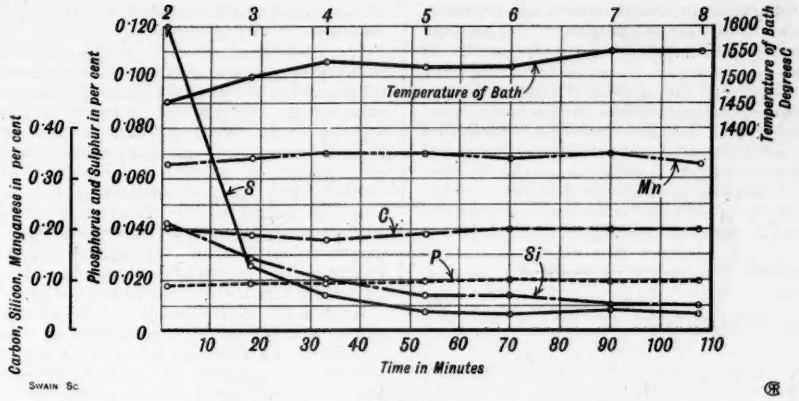


FIG. 2

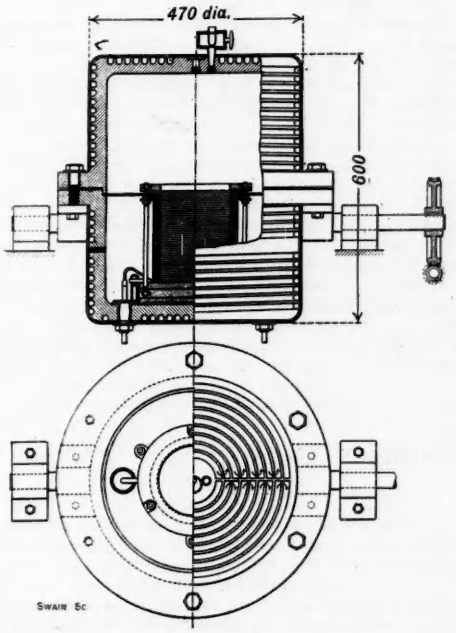


FIG. 3

Provision is also made for casting in vacuo. For this purpose a mould is fixed in the upper part of the vacuum vessel in such a position that liquid metal from the crucible is poured into it when the whole furnace with its casing is tilted about a horizontal axis. A number of spiral grooves are cut in the outside surface of the vacuum vessel and sealed with zinc sheeting in order to provide facilities for water cooling. This is necessary, as a certain amount of energy is dissipated as heat in the steel casing while the inductor coil is energised.

The furnace is evacuated by means of a four-stage mercury diffusion pump, which is " backed " by three rotary oil pumps (each of 5 cubic metres per hour capacity), arranged in parallel. Three reservoirs of 120 litres total capacity are interposed between the diffusion and the rotary pumps, so as to restrict the pressure rise in the low vacuum system in the event of a sudden evolution of gas in the furnace. When energised by means of the high-frequency generating equipment at the Kaiser Wilhelm Institute, the efficiency of the steel-cased vacuum furnace compared favourably with that of a furnace of the non-vacuum type. Presumably the extra losses due to the presence of the steel vessel were more than balanced by the elimination of convection losses associated with air melting.

In a trial conducted with a charge of cast iron, the pressure in the cold furnace was reduced by the action of the vacuum pumps to 0·06 mm. in 35 minutes. On switching in the furnace a considerable rise in pressure occurred before the metal charge attained a red heat and reached a maximum of 20–30 mm. during the actual melting of the metal. On holding the charge liquid, the pressure fell rapidly until the initial value of 0·06 mm. was approached. At this stage the charge was allowed to cool.

The author attributes the rapid degassing action of the furnace to the electrically produced circulation of the metal bath, a phenomenon which is responsible for the rapid replacement of metal exposed to the influence of the vacuum at the top surface of the liquid. A number of charges, including nickel, cast iron, and steel, were subjected to the degassing process in the furnace, and estimates made of the

oxygen and total gas in the metal, both before and after treatment. These determinations were made by the "heat extraction method,"* and in all cases considerable reductions in both the oxygen and total gas content are recorded.

It is suggested that the furnace with slight modifications could be utilised for the preparation of melts in controlled atmospheres and at pressures up to 50 atmospheres.

It may, however, be pointed out that a furnace inductor coil operating within a vacuum vessel would probably give rise to serious glow discharges if the potential difference between the ends exceeded a few hundred volts. It therefore appears desirable to energise a furnace of the type described by the author by means of continuous or nearly continuous oscillations of moderate frequency.

X-Ray Examination of Wire Ropes.

THE X-ray examination of wire ropes, especially with a view to detecting the occurrence of internal corrosion, presents some special difficulties owing to the shape of the rope. If an attempt is made to obtain an X-ray photograph in the ordinary way an intensity of radiation sufficient to penetrate the full diametral thickness of the rope produces violent over-exposure of the outer portions, which, of course, present a much smaller thickness of metal to the passage of the rays. The result is general fogging of the film. Methods for overcoming this difficulty and results obtained are described in a paper by Glocker, Wiest and Woernle, of Stuttgart, in the issue of *Stahl und Eisen* for July 20th last. The method they adopt is to immerse the sample of wire rope in a solution of high density and therefore of great absorbing power for X-rays, the ideal condition being that the solution should have the same absorbing power as the material of the rope itself. This requires the use of strong solutions of salts of metals of high atomic weight. Barium chloride and barium iodide have been used, but the latter, although satisfactory in many ways, is prohibitively expensive for technical purposes. The authors have tried a variety of solutions, and this has led them to the use of lead chlorate and tin chloride. ' Barium chloride proved to be insufficiently absorbent. Lead chlorate was better, but cannot be used on account of the secondary radiation from the lead, which causes a general fogging of the film. The most favourable results were obtained with tin chloride. The outlines of the immersed object are sharp in the photographs, because the secondary radiation from the tin can be absorbed by a filter $\frac{1}{2}$ mm. in thickness of copper. Actually, however, the container in which the liquid and the immersed object were placed proved sufficient as a filter. It was made of tinned sheet steel $\frac{1}{2}$ mm. in thickness. The aluminium base of the slide in which the film was contained, also having a thickness of $\frac{1}{2}$ mm., acted as a further useful filter.

The use of aqueous tin chloride solution containing about 70 per cent. $SnCl_2$ requires certain precautions. The solution is a very strong reducing agent, and any traces of it reaching the photographic film would cause black spots. It, therefore, becomes desirable that the operator working with the tin chloride solution should have nothing to do with the handling and developing of the films. Also, aluminium cannot be used as a container, because it is readily attacked by the tin salt; a suitable material is tin sheet steel. The wire ropes themselves must be protected against penetration by the solution, and for this purpose brief immersion in a bath of molten paraffin has been found satisfactory.

Provided that correct exposure to X-rays of suitable hardness is given, and that photographs are taken with the radiation passing through the wire rope along different diameters, very interesting results can be obtained. It was anticipated at the outset, and it has been realised in practice, that it is impossible to observe the reduction of diameter of individual wires or strands of the rope as the result of corrosion. It has, however, been found that there are certain typical differences in the photographs taken from new or entirely sound ropes and from those in which internal corrosion has occurred. These arise from the fact that in a sound rope the arrangement of the wires or strands, particularly where a hemp core is employed, is such that at certain points there is, from the X-ray standpoint, a clear view between the wires, obstructed only by the hemp core itself. These clear spots appear as dark patches on the photograph, and in a new or sound rope form a continuous spiral line. Where, however, there has been appreciable internal corrosion, which may not be at all visible from an external examination of the rope, the clear view through these slots is more or less blocked by the products of corrosion. The result is a blurring of the lines of the spirals just mentioned which makes itself clearly evident on the X-ray photograph.

The authors give a number of interesting examples taken from ropes in various conditions, and they claim that, especially when stereoscopic X-ray photographs are employed, it is possible to detect internal corrosion with considerable certainty. In order to facilitate this method of examination and to render it more sensitive, the authors introduce into the construction of the ropes certain "corrosion wires," which render the interpretation of the X-ray photographs still more definite. Their work furnishes an interesting example of the way in which specialised problems can be attacked and solved by means of X-ray technique; their results are likely to be of considerable importance for the actual inspection of wire ropes after certain periods of service, but they may prove even more useful as an example of the way in which such methods are capable of application.

Damping Capacity and Fatigue Strength.

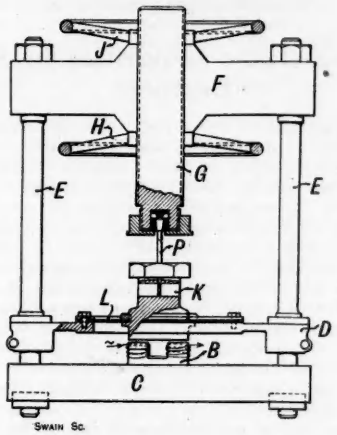
DURING the past few years German workers on fatigue have given considerable attention to that rather peculiar but interesting property of metals which they call damping strength or damping capacity, and two recent papers on this matter, one by E. Voigt and K. H. Christensen, of the Kaiser-Wilhelm Institute at Düsseldorf,* and the other by E. Bankwitz,† of the Wöhler Institute at Brunswick, form the subject matter of the present review-

* W. Hessenbruch and P. Oberhoffer, Arch. Eisenhüttenwes. 1, 1927/28, p. 583/603.

* Mitteilungen aus dem Kaiser-Wilhelm-Institute für Eisenforschung Band, XIV, 11, 1932.

† Metallwirtschaft Metallwissenschaft Metalltechnik, 20th January, 1933, p. 33.

abstract. Before considering these papers in detail, however, it may be worth while to point out that damping capacity can be defined as that property of a material which enables it to absorb energy when subjected to repetitions of stress. Accordingly a study of damping capacity really consists of detailed examination during stress repetitions of that behaviour which, in this country, would be known as hysteresis changes. The subject, therefore, is far from new, but the modern German workers are endeavouring to deal with it in a more quantitative manner than has hitherto been the case. Foeppl, for example, has determined damping capacities in torsional fatigue in terms of energy absorbed in kilogramme centimetres for each reversal of stress per unit weight of material. The practical value of such work is largely concerned with the ability of materials to absorb energy under resonance conditions and when overloaded for a few stress cycles; on the theoretical side, the work may prove useful in the



REPETITION OF STRESS TESTING MACHINE

relation between energy absorption and initiation of fatigue failure.

The primary object of the work of Voigt and Christensen was to compare the damping capacities of a number of steels at stresses of the same order as the fatigue limits of the materials. In order to avoid the obvious disadvantages of the non-uniform distribution of stress in torsional and bending fatigue tests their work was carried out by means of direct tension-compression fatigue. The testing machine they used appears to be very ingenious and worthy of description.

The machine, illustrated above, consists of a heavy mass F, with a spindle G, to which the upper conical end of the test specimen P is attached. The mass F is connected by columns E to the mass C, which carries the electro-magnets B. The lower end of the specimen is attached to the armature K, which is guided by the diaphragm L. The magnet air gaps can be altered by adjusting the position of the diaphragm L on the columns. The feet of the machine rest on rubber blocks in order to avoid dissipation of energy to the foundations. The magnets are supplied with alternating current at a frequency equal to the natural frequency of the moving system (specimen, armature and diaphragm), approximately 435 cycles per second. This is accomplished by means of a valve oscillator, the stress on the specimen being varied by altering the working conditions of the valve; the mechanical and electrical systems are kept in resonance by the strong coupling existing between them. In addition, there is a direct-current winding on the magnets so that a steady mean stress can be superimposed on the alternating load due to the alternating current; interaction is prevented by means of a choke coil.

In carrying out a damping test the motion of a scratch on a mirror attached to the armature is recorded micro-photographically. The alternating and direct currents are broken simultaneously and the resultant record shows the rate of decay of the oscillations, from which the logarithmic decrement, and so the damping, can be obtained. A correction for damping extraneous to the specimen, *e.g.*, air resistance, is applied. In order to use the machine for the determination of the fatigue limit, it was found necessary, on account of the high speed, to cool the specimens during tests. Thin lubricating oil was used for this purpose, and was led to a chamber surrounding the specimen. Even when so cooled the temperature in one case rose 80 deg. Cent.

The steels used by Voigt and Christensen in their experiments are indicated in Table I. In regard to

TABLE I.

Material (all steels).	Ultimate tensile stress, tons per square inch.	Modulus of elasticity (static), lb. per square inch.	Fatigue limit reversed direct stress, σ_w tons per square inch.	Fatigue limit reversed bending, σ_{wB} tons per square inch.	$\frac{\sigma_w}{\sigma_{wB}}$
C	36·8	$29·9 \times 10^6$	16·5	14	1·18
CrNi	57·5	29·2 „	35	30	1·17
CrNi	57·8	29·2 „	38	—	—
CrV	44·5	29·1 „	21	23	0·92
CrV	49·5	29·0 „	26	25	1·03
CrMo	49·5	29·5 „	26	26·5	0·98
CrVMo ..	51·8	29·1 „	26	25	1·03
VCN 45 ..	54·2	29·8 „	29	25	1·13
StC 60·61 ..	42·1	29·5 „	22	21·5	1·03
St 37	23·4	29·9 „	15	13	1·12
St 52	33·3	29·8 „	23	21	1·09

the primary object of the work, viz., comparison of damping capacity, the results, although given in considerable detail in the paper, are too indefinite to call for detailed consideration in the present abstract. They devoted considerable attention to change of damping capacity when a constant stress cycle was repeated a large number of times, but found that alterations in damping capacity under such conditions did not follow any definite laws, since in some cases increases, and in other cases decreases, occurred with increase in the number of stress reversals. They found, however, that the damping was constant in the plain steels below the fatigue limit, whilst in tempered and alloy steels it increased steadily at stresses above the fatigue limit. In general, the plain steels showed greater damping capacity than the alloy steels, and in the tempered and alloy steels the damping was largely dependent on the previous stressing of the particular specimen under test.

In the course of their work Voigt and Christensen determined actual endurance fatigue limits of the various steels both at high frequencies in their own machine and by rotating bending tests in a Schenk machine. These results are also shown in Table I. and are perhaps of more interest than the damping

experiments. Normally, the ratio of direct stress fatigue limit to bending stress fatigue limit varies from about 0·75 to 1·0 according to the material being tested, but in Table I. it will be seen that the ratio exceeds 1·0 in a number of cases. The abnormality of these results was noted by Voigt and Christensen, and they carried out interesting experimental and analytical work, which, in their view, explains the high values obtained in the direct stress fatigue tests. The main points to consider in comparing the direct stress and bending stress fatigue values are the speed of test, roughly 27,000 reversals per minute in the former and 3600 reversals per minute in the latter, and the fact that in the former case the specimens were cooled by means of an oil stream. The loads in the direct stress machine were obtained by means of static calibrations, and the authors not only attribute the abnormal values to a speed effect, but have developed a method whereby allowance can be made for the speed effect and the correct direct stresses obtained. In brief, it can be assumed that the load application is sinusoidal, and an approximately correct differential equation can be derived for the vibrations, which includes the effect of the damping due to air resistance and to hysteresis forces in the specimen. The stiffness of the vibrating system can also be obtained by static loading experiments so that the natural periodicity without any damping effects can be calculated. (The calculation was checked by experiments with diaphragms of different stiffnesses.) The experimental work showed that the actual frequencies of the vibrations in the direct stress tests were always less than those calculated from static calibrations, and Voigt and Christensen ascribe the differences to changes in the stiffness of the test specimens under the test conditions; in other words, the normal static value of the modulus of elasticity of the test material does not apply to the experimental conditions. Further, from the equation of motion and the experimental observations, a corrected value of the ratio of stress to strain under the test conditions can be obtained, and from this the correct stresses in the test material can be calculated. The methods of calculation and results obtained appear to be reasonable, and are certainly of interest to students of fatigue; the corrected results obtained are shown in Table II., and it will be noted that the ratios of direct stress to bending stress fatigue limits are more or less normal.

TABLE II.—*Corrected Modulus and Fatigue Values.*

Material (all steels).	Speed of test, reversals per second.	Derived value of modulus, lb. per square inch.	Corrected fatigue limit reversed direct stress, σ^1_w tons per square inch.	$\frac{\sigma^1_w}{\sigma_{wB}}$ (Table I.).
C	422	$23{\cdot}0\times10^6$	12·9	0·93
CrNi	435	24·8 ,,	29·1	0·98
CrNi	430	23·7 ,,	30·2	—
CrV	437	24·7 ,,	18·0	0·79
CrV	433	24·1 ,,	21·0	0·83
CrMo	437	24·7 ,,	22·3	0·84
CrVMo	437	24·7 ,,	21·5	0·85
VCN 45	429	24·0 ,,	23·4	0·92
StC 60·61 ..	436	25·0 ,,	18·9	0·87
St 37	425	23·4 ,,	11·9	0·90
St 52	417	22·4 ,,	16·4	0·79

The work of Bankwitz is on rather different lines from that of Voigt and Christensen, one particular object of his work being to develop a method suitable for the measurement of damping in torsional fatigue at very low stresses. The apparatus he used consisted of a horizontal torsion specimen, to the free end of which discs were attached, and to the other end of which oscillations of constant amplitude could be applied. The speed of oscillation which coincided with the natural frequency of the test specimen and discs was observed, and by a series of tests at various settings of the applied strain oscillations, curves of damping effect were obtained against torsional strain, since the damping or hysteresis effects reduced the natural frequency of the specimen with the end discs. Bankwitz considers that the method is very sensitive for observing damping effects at low stresses. Tests were made on a number of ferrous and non-ferrous metals; the general conclusion drawn from the work was that for torsional stress cycles applied at speeds varying from 200 to 2500 cycles per minute the elastic and plastic behaviour was independent of the rate of strain.

Non-metallic Impurities in Steel Castings.

A PAPER was recently read before the Association Technique de Fonderie by Dr. F. Giolitti[1] on "Non-metallic Impurities in Steel Castings." As is well known, Dr. Giolitti has devoted much attention to the study of non-metallic inclusions in steel, and as long ago as 1915 propounded a theory[2] (which in its application to steel castings is re-stated in this paper) to account for the ferrite bands commonly observed in steel. He bases this on the assumption that inclusions normally exert a decarburising action on the metal surrounding them, thus reducing the carbon content of the austenite. The ferrite first formed in these low carbon areas acts as a nucleus for the progressive accumulation of the rest of the ferrite, which separates as cooling proceeds. Since manganese sulphide, one of the commonest inclusions in steel, does not itself possess oxidising properties, an alternative view has been put forward that all inclusions (assumed to be soluble in liquid steel)[3] are, after solidification, to some extent soluble in the surrounding metal. At high temperatures the adjacent austenite would then be saturated with the substance of the inclusion and its solubility for carbon correspondingly reduced. When ferrite is then deposited on cooling it will first form on the low-carbon areas surrounding the inclusions[4]. Whilst not denying the contention of Ziegler[5] and of Steinberg[6] that pure sulphides may separate from solution in liquid steel, Giolitti dissents from the view that artificially produced inclusions of this type are similar to those present in practice. He describes an experiment in which he found that the non-metallic inclusions in a sample of steel weighing several kilogrammes, taken from a very hot bath of metal, and quenched in water from the liquid state, were identical in character,

[1] Giolitti, Bulletin de l'Association Technique de Fonderie, 1933 (May), 7, 167.

[2] Giolitti and Zublena, Internationale Zeitschrift für Metallographie, 1915, 7, 35.

[3] Howe, "Proceedings" of the American Society for Testing Materials, 1911, 11, 271.

[4] Mahin and Botts, *Chemical and Metallurgical Engineering*, 1922, 27, 980.

[5] Ziegler, *Revue de Métallurgie*, 1911, 8, 655.

[6] Steinberg *Revue de Métallurgie*, 1914, 11 (extracts), 313.

dimensions, frequency and distribution with those in the same steel slowly cooled and examined in the "as-cast" condition and after thermal treatment. This conclusion is, however, at variance with the experience of Sims and Lillieqvist,[7] who regard it as an established fact of great practical importance that non-metallic inclusions are largely soluble in liquid steel.

Dr. Giolitti, following Benedicks and Löfquist,[8] classifies the inclusions present in steel as (1) mechanically admixed inclusions the presence of which is accidental (Benedicks' "foreign slag particles"), and (2) inclusions of non-metallic matter arising from reactions taking place in the molten and solidifying steel (Benedicks' "native slag particles"). Among inclusions of the second type he distinguishes between particles large enough to be identified when seen under the microscope, and "emulsified" inclusions. The latter are identical in nature and origin with those visible under the microscope, but distinguished from them by greater dispersion, and by chemical changes that they have undergone owing to the action of the metal with which they have been in contact.

The effect of these inclusions is dealt with under several headings :—

Quantity.—Since the total effect is clearly the resultant of the individual effects of each particle, quantity must count ; but nevertheless other factors may predominate and the adverse effect of a small number of inclusions may be more pronounced than that of a larger number which are individually less harmful.

Dimensions.—Although in forged and rolled steel even very highly dispersed inclusions can give rise to marked changes in mechanical properties, in cast steel inclusions whose degree of dispersion exceeds a certain limit (corresponding to a limit of visibility at a magnification of 200 to 300 diameters) do not appear to produce any marked effect.

Form.—Form is only of importance when the dimensions exceed the limit given above, and the effect is more harmful when the particles are elongated or lamellar rather than globular.

Distribution.—In cast steel, the distribution of the inclusions in relation to the primary structure is important. An example (previously described by Giolitti)[9] is given of the spontaneous cracking of a slightly forged ingot of 2 per cent. nickel steel. Examination revealed that the fracture had occurred between a region of pronounced dendritic structure (C, 0·44 ; P, 0·034 per cent.) and one in which the structure was granular (C, 0·30 ; P, 0·018 per cent.) and through a boundary in which numerous non-metallic inclusions had coalesced to form large non-metallic masses, whereas in the rest of the steel the inclusions were normal in quantity, distribution, and properties.

Reactions.—In Giolitti's opinion the harmful effect of inclusions in cast steel is specially shown when the inclusions (whether large or emulsified) have a strongly oxidising effect. The decarburising reactions between the inclusions and the surrounding steel are held to have an important effect on the properties of steel castings, giving rise to marked lowering of the elastic limit, reduction of area, impact figure, and resistance to fatigue.

[7] Sims and Lillieqvist, American Institute of Mining and Metallurgical Engineers, 1932, Technical Publication No. 453.

[8] Benedicks and Löfquist, "Non-metallic Inclusions in Iron and Steel."

[9] Giolitti, *Chemical and Metallurgical Engineering*, 1920, 23, 149.

In considering methods whereby the influence of non-metallic inclusions may be reduced to a minimum, Dr. Giolitti proceeded to discuss the effect of modifications of furnace practice, following the lines of his paper[10] on "The Complex Action of Manganese and other So-called Deoxidising Agents Used in the Manufacture of Steel." He reaffirmed his belief that the specific action of manganese on inclusions in steel is exactly comparable with the coagulating action of certain electrolytes on colloidal solutions. In accordance with this view and on the basis of his experience he states that although other deoxidising agents (silicon, for example) may be used, the presence of manganese is still necessary for the complete purification of the metal, and that this purification is only brought about when a manganese content above a certain limit is continuously maintained in the bath, a relatively low percentage of manganese maintained for a long time being more effective than greater additions made only towards the close of the operation. To reduce the harmful effect on the final product of inclusions present in the liquid steel, the adoption of a low casting temperature and of means to produce rapid solidification are recommended as likely to increase the number of primary nuclei of crystallisation formed in the steel, and so prevent local accumulation of non-metallic inclusions.

If well deoxidised steel is employed and precautions are taken, by suitable casting conditions, to eliminate the effect of inclusions, their influence, according to Giolitti, ceases to be harmful. On the other hand, he states that in badly deoxidised steel, even if all means are taken to eliminate the segregating effect of a coarse primary structure on the distribution of inclusions, their harmful influence is always shown in the secondary crystallisation, and consequently on the mechanical properties. Even then, however, the harmful effect can be diminished by treatment which involves rapid cooling, *i.e.*, normalising or quenching. Results of mechanical tests are given to indicate the character of the improvement brought about, and this improvement appears to be attributed by Giolitti wholly to the suppression of the bad effect of inclusions. The justification for this claim is, however, not apparent, as it will readily be recognised that improvement by normalising or heat treatment is the result of structural changes throughout the mass of the steel, especially in the character and proportion of the pearlite, and is not mainly governed by changes which occur in the vicinity of the inclusions. A comparison of the effect of treatment on two steels (one "dirty" and the other relatively free from inclusions) would have been valuable in indicating how far the treatment suppressed, or how far the enhanced properties merely masked, the harmful effect of the inclusions. It seems unfortunate, therefore, that Giolitti definitely states that he regarded information about the effect of treatment on well deoxidised steels as outside the scope of his paper.

A point of interest which was raised in the discussion deserves mention. Monsieur Lemoine, of L'Ecole Supérieur de Fonderie, Paris, referred to the possible effect of inclusions on the fluidity of steel. He remarked that fluidity was reduced if the steel was left at rest under a white slag, and that appreciable differences in fluidity were obtained according to the order of charging the silicon and manganese. Distinguishing between "immediate" fluidity and

[10] Giolitti, *Journal* of the Iron and Steel Institute, 1923, (2), 108, 35.

the duration of a fluid condition (capacity for running), he stated that if acid and basic steels, containing equal amounts of inclusions, were compared, the basic steel would be found to be more fluid, but the acid steel would retain its fluidity longer and so fill a mould better. Such generalisations as these raise points of great importance, but their possible connection with the character of the inclusions present was not further elucidated.

Metals Melted in a Vacuum.

IT is a pleasant custom among many German firms and institutions to issue a commemorative volume when they have occasion to celebrate an anniversary. We have before us at the moment an excellent example of this form of literature, which is partly commemorative and informative, but undoubtedly also to some extent propagandist in nature, in the form of a small book, entitled "Heraeus Vacuum Schmelze," 1923–1933.

As is usual in most publications of this type, it includes papers by a number of authors, some of them definitely attached to the firm in question and others working on lines of investigation planned in friendly collaboration with the firm and its work. While these papers are of considerable interest, it is probable that most readers who are concerned with metallurgical development will be chiefly attracted by the account, given at the beginning of the book and occupying some 73 pages, of the development of the concern itself—an account written by Dr. W. Rohn, who is personally well known in this country. This history of development and progress from a purely laboratory experiment to a manufacturing enterprise on a considerable scale is of special interest, because it illustrates the fact that an enterprising firm can frequently produce a profit-making manufacturing process by the direct development of research apparatus. The refinement of melting in vacuo was first employed by the well-known firm of Heraeus as manufacturers of platinum and other thermo-couples for the purpose of producing on a very small scale metals and alloys of special purity and constancy of composition to allow of their use for thermo-couples in substitution for platinum and its alloys. From these laboratory efforts industrial processes of melting and casting in vacuo have been developed.

In the present book Dr. Rohn is able to describe furnace plant capable of dealing with 4-ton charges, while at the same time rod rolling and wire-drawing plant has been developed on novel lines. In this connection it is interesting to note that the technique of melting in a high vacuum was also developed, quite independently, in this country by means of the high-frequency induction furnace which was first used for this purpose at the National Physical Laboratory. British manufacturers, however, regarded this method of working as a laboratory toy which could not possibly be adapted for practical work on a large scale. We cannot therefore deny our measure of admiration for the enterprise and perseverance of the firm who have brought this process to practical fruition.

As might be expected in a book of this kind, many of the papers reproduced are designed to show the advantages of alloys prepared by vacuum melting. One particularly interesting instance is that of certain alloy wires intended for use in the construction of dentures. The artificial teeth for dentures are attached, as is well known, to the gold alloy or other metallic framework of the denture, by means of small wires which are embedded in the material of the tooth. This material very closely resembles, before the tooth is fired, a mass of finely powdered glass in which the little pieces of wire are embedded while in the mould. The teeth thus moulded are then fired at a sufficiently high temperature to produce the desired texture and the embedded wires should be firmly held in the vitrified tooth. While it was possible and usual to employ platinum for this purpose, little difficulty was encountered, but with nickel-chromium alloys there is a strong tendency for the wires to be only loosely attached to the vitreous mass, and it was discovered, both in this country and in Germany, that the difficulty was due to the formation of air or gas bubbles around the wires. It is claimed that if the wire is made of metal which has been melted in vacuo there is no such development of bubbles, the explanation being that the gas which produces them is derived from the metal of the wires. While there may be other methods of overcoming this difficulty, the explanation and remedy offered by the German workers is undoubtedly interesting. Whether these claims are or are not borne out by the ultimate test of prolonged practice remains to be seen, but it is evident that the German firm now celebrating its tenth anniversary has achieved remarkable success in developing a new technique on a commercial scale. This new technique may be expected to make it possible for it to produce materials which cannot be obtained by other means.

Magnetic Fields and the Hardness of Metals.

IN 1930 Herbert submitted a paper to the Royal Society in which he claimed that by rotating metal specimens in magnetic fields, changes in the hardness of the specimens could be observed. Herbert used a pendulum tester of his own design in measuring the hardness changes. His results are of considerable interest in the study of the fundamental facts of hardness, and because of this interest, Esser and Cornelius* have recently carried out further work on the subject with the main object, apparently, of confirming or disproving Herbert's experimental results.

In the first part of their paper, Esser and Cornelius briefly discuss recent researches and suggestions on the effect of electromagnetic fields on the physical characteristics of metals and alloys. They mention, among other matters, that in their opinion the behaviour of certain materials in a strong electromagnetic field of high frequency can be explained by the work theory of Zwicky, if it be assumed that the crystals are formed of lattice blocks more or less strongly oriented in the same direction, which act as elementary magnets, and that between these blocks there are formed fine submicroscopic canals, which act as paths for diffusion. They then give a summary of some of the results obtained by Herbert on hardness changes produced by magnetic fields, and proceed to describe a series of tests in which they have

* H. Esser and H. Cornelius, Metallwirtschaft, April 14th, 1933, Vol. 12, No. 15, pp. 210–213.

endeavoured to repeat part of Herbert's experimental results. The apparatus used by Esser and Cornelius consists of a water cooled electromagnet with conical pole pieces (100 mm. diameter, tapering to 10 mm.), with a pole gap of 40 mm. A central spindle enables the test piece to be rotated in the magnetic field. Tests were carried out using fields of 6750 and 9500 gauss, the specimens being rotated slowly. Hardness tests were made with the Herbert pendulum, several individual readings being taken for each recorded value. The materials investigated were eight carbon steels, with carbon contents ranging from 0·5 to 1·5 per cent., and with not more than 0·2 per cent. of further alloying element. A cloudburst treatment (apparently by the method developed by Herbert) was also applied in some of the experiments. The effect of rotation in a magnetic field on the hardness of these steels was somewhat variable. Fluctuations in hardness were obtained which varied uniformly with time, but they were usually within the limits of error of measurement and were such as would be obtained in ordinary tests on a hard steel. Rockwell tests before and after each complete experiment showed no positive results other than a slight increase in hardness attributable to the effect of the cloudburst treatment.

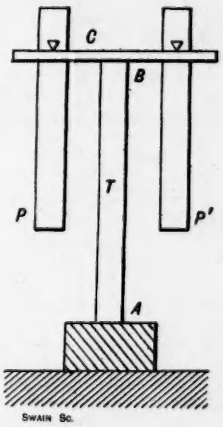
A special series of tests showed the pendulum hardness tester to be very sensitive to temperature effects. It was found that warming one side of the instrument rendered exact measurements impossible ; even when the room in which the pendulum was used was heated uniformly, the results of the tests were affected. In experiments to determine the effect of temperature on the pendulum, it was found that at 19·5 deg. Cent. the pendulum gave a hardness reading of 101 on the standardising glass plate ; at 22 deg. Cent. the hardness reading on the plate was 107 ; and at 24·5 deg. Cent. the reading was 111. Esser and Cornelius attribute the dependence of the pendulum readings on temperature to the complicated form of the instrument, and to the fact that materials of differing coefficients of expansion have been used in its construction.

As a further check on Herbert's results, pendulum tests were made to determine the effect of rotation in a magnetic field on the hardness of a 1·18 per cent. carbon steel, the complete series of tests being made in a constant temperature room to avoid temperature errors in the pendulum readings. The same magnetising apparatus as before was used in this work, but in order to reproduce Herbert's tests as closely as possible the test piece was used to bridge the gap between cylindrical pole pieces, and so was rotated lying on top of the pole shoes. The results showed no effect of the magnetic treatment (field of 16,000 gauss) on the hardness other than a slight rise with time, attributable to the ageing which occurs most strongly shortly after quenching. A number of tests using a Rockwell hardness tester were also carried out on carbon and alloy steels in order to determine whether this method of test indicated hardness changes as a result of magnetic treatment. In these cases also there was no sign of any effect of the magnetic treatment.

Esser and Cornelius summarise their experiments by saying that in spite of using consistent test conditions, particularly in experiments involving Herbert pendulum hardness tests, there were no detectable variations in the hardness of hardened steel specimens with time, when subjected to the effects of a strong magnetic field. This could not be accounted for by the fact that the apparatus and test conditions used by them were not similar to those used by Herbert. However, in their opinion, the question as to whether magnetic fields would affect the process of separation within a crystal lattice has not been negatived ; the nature of the field seemed to be of importance, and high-frequency fields especially might be of outstanding importance in affecting the rate of diffusion and separation within solid metallic bodies.

A New Method for the Measurement of the Modulus of Elasticity.

THE modulus of elasticity is one of the fundamental constants representing a physical property of a material, but its measurement usually involves the use of a delicate extensometer to measure extensions and considerable care in loading so as to produce uniform stress distribution ; the values obtained may also be complicated by hysteresis effects in the test material. Accordingly, considerable interest attaches to a dynamic method for modulus determinations recently developed by Le Rolland and Sorin,* by which it is claimed that the usual practical difficulties are avoided. The principle of this method is illustrated below. A test piece of rectangular section



firmly fixed in a vertical position by its lower end A carries a horizontal platform C which bears the knife-edges of two identical pendulums P and P^1. If P is at rest and P^1 is set swinging, the small horizontal reactions of the pendulum P^1 produce small elastic deformations of the test bar T, which in turn set in motion the pendulum P. As the energy of P^1 passes to P the amplitude of the latter increases and the amplitude of P^1 decreases until finally it comes to rest. The energy transfer then begins in the opposite direction until P comes to rest again. The observed quantity is the time τ which elapses between two successive arrests of the same pendulum. In practice,

* "On a New Method for the Measurement of the Moduli of Elasticity of Materials," by MM. P. Le Rolland and P. Sorin *Revue de Métallurgie*, March, 1933, p. 112.

by measuring the time of a number of these periods, the precision of measurement can be increased as desired.

If the test bar has breadth b and thickness d in the plane of bending, and the length between the point of support A and the plane of the knife-edges is l, the "rigidity" K of the bar, defined as the ratio of the end load to the static end deflection, is given by the expression :—

$$K=\frac{3\,E\,I}{l^3}=\frac{E\,b\,d^3}{4\,l^3},$$

where I is the moment of inertia of the section. It is the value of K which determines the amplitude of movement of the end of the test piece caused by the reactions of the pendulums, and hence the value of τ. Suppose the pendulums have each a mass M and period T. The effect of radius of gyration of the pendulum is by no means negligible. From considerations of stability, cylindrical pendulums were used having a radius of gyration equal to the distance from the centre of gravity to the axis. With these pendulums the relation between K and τ is given by

$$K=\frac{2\,\pi^2\,M}{T^2}\left(\frac{\tau}{T}+\frac{2\,\mu}{M}\right)$$

in which μ is the equivalent mass of the test piece. For a test piece of mass m fixed in the manner considered

$$\mu=\frac{33}{140}\,m.$$

In general, τ is large compared with T and the pendulums can be made heavy so that $2\,\mu/M$ is negligible, in which case

$$K=\frac{2\,\pi^2\,M}{T^2},$$

which gives the modulus of elasticity as

$$E=\frac{8\,\pi^2\,M\,L^3}{T^2\,b\,d^3}.$$

More generally, if A is the pendulum constant, such that $K=A\,\tau$, then

$$E=\frac{A\,L^3}{3\,I}\,.\,\tau.$$

In practice a correcton for the effect of the platform C is necessary.

The method of test may be varied by using elastic vibrators, which, however, suffer from rapid damping, or by supporting the test piece as a beam. Expressions similar to the above may be found for these cases.

Experiments of this type on standard cast iron bend test pieces, $35\times8\times10$ mm., were found to give values of E lower than the true value. The reason for these fictitious values was found to be the short unsupported length of the test piece (20 mm.) compared with the cross section. In short test pieces the effect of the end fixing becomes too important, and correction for this is impossible.

In the paper an example of a test on an aluminium specimen is worked out, and in addition a table of values of E for steel, duralumin, bronzes and cast irons, determined by this method, is given. These show good agreement with values found by a Martens extensometer, which are given for comparison.

The advantages claimed for this dynamic method of measuring modulus of elasticity are :—

(1) Measurements of load and extension are replaced by a single time measurement.

(2) The test piece has time to settle down under alternations of loading and give a true value of the modulus.

(3) As the oscillations are extremely small, the modulus is that at the origin of the stress-strain curve. Experiments with the test piece initially under slight tension have shown no appreciable difference from the normal experiments in which they are under slight compression, due to weight of the pendulums.

(4) The method is accurate provided the test piece is of sufficient length. Accidental shocks during the test have no effect on the results.

The Testing of Welds.

THE search for satisfactory and non-destructive methods for testing welds, especially in steel, continues with great activity, and a number of methods have been proposed. An account of an interesting development of these methods was recently given at a meeting of the Verein deutscher Ingenieure, which was held in May last, by S. Kiesskalt, of Frankfurt. A brief account is given in *Stahl und Eisen* for July 13th, page 742.

W. Gerlach* suggested that the magnetic flux which emerges at right angles from the surface of a steel body in which there is a discontinuity can be made to induce current in a moving coil, and such current can be measured ballistically. Kiesskalt and Schweitzer have developed from this suggestion a method for testing welds which makes use of an oscillating coil for continuous testing. The detecting and measuring coil is contained in an implement, which can be moved over the surface of the steel, and the magnetic component, at right angles to the surface of the steel is caused to produce electrical oscillations, either because the testing coil is maintained in undamped mechanical oscillation parallel to the steel surface, or because an iron core lying within the coil is made to oscillate in a direction at right angles to the surface of the steel under test. These undamped vibrations either of the coil or of the core are produced electro-magnetically by alternating currents, whose frequencies correspond to audible musical notes. Quite small changes in the magnetic component at right angles to the surface of the steel produce changes in the intensity, but more especially in the quality of the audible note produced by the currents in the measuring coil. External disturbances can be, to a large extent, minimised by placing two coils in the instrument and connecting them so as to oppose one another in regard to disturbing effects. The exciting magnetic field is produced by two permanent bar magnets. The whole apparatus is arranged in portable form, weighing less than $8\frac{1}{2}$ kilos.

It is, of course, impossible to offer any opinion as to the value of such a method until it has been very thoroughly tested. At first sight, it seems likely that a definite fissure at or close to the surface along which the testing coils are moved would readily make itself felt in the manner described. Whether a defect at a greater depth and perhaps forming a longitudinal rather than a transverse fissure would be detected is less certain, and the difficulty would increase with the thickness of the weld under examination. The principle of the method is, however, interesting, and its development deserves careful consideration.

* "Metallwirtschaft," 8 (1929), page 875/77.